Jets and electroweak bosons measured in p+Pb and Pb+Pb collisions with ATLAS

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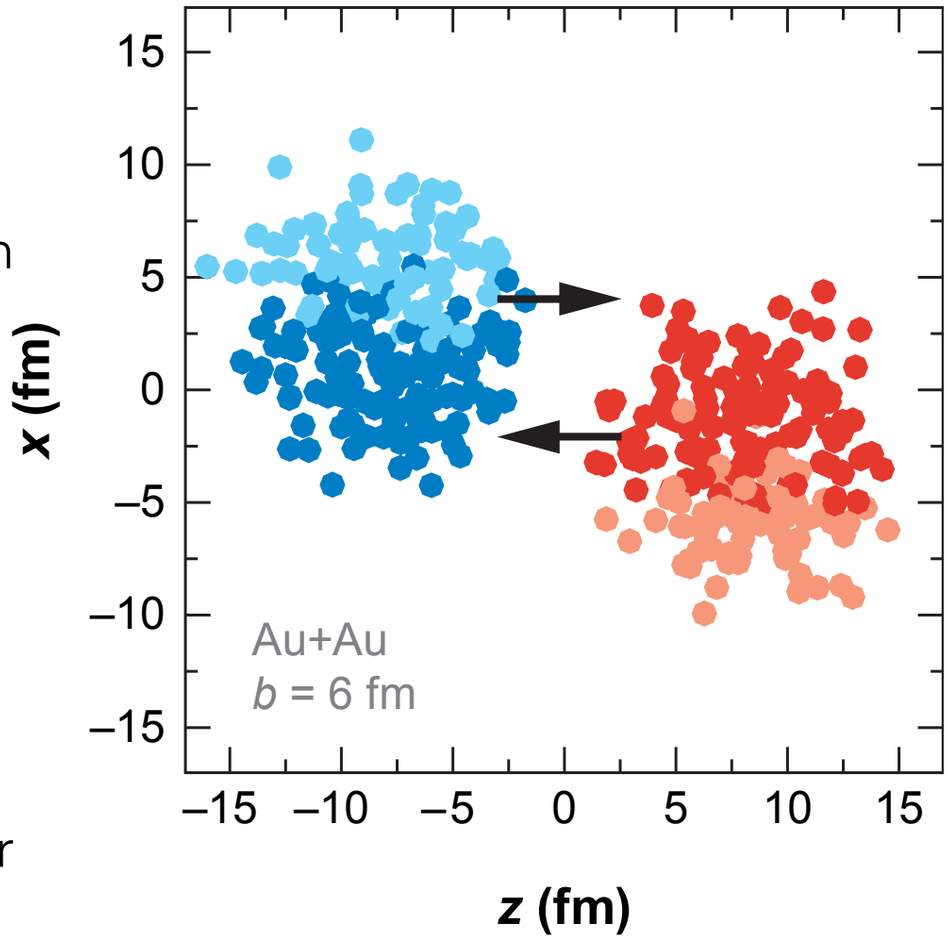
Hard process rates in A+B

- In HI and p+Pb, expect scaling of hard processes with nuclear thickness (calculated using Glauber modeling)

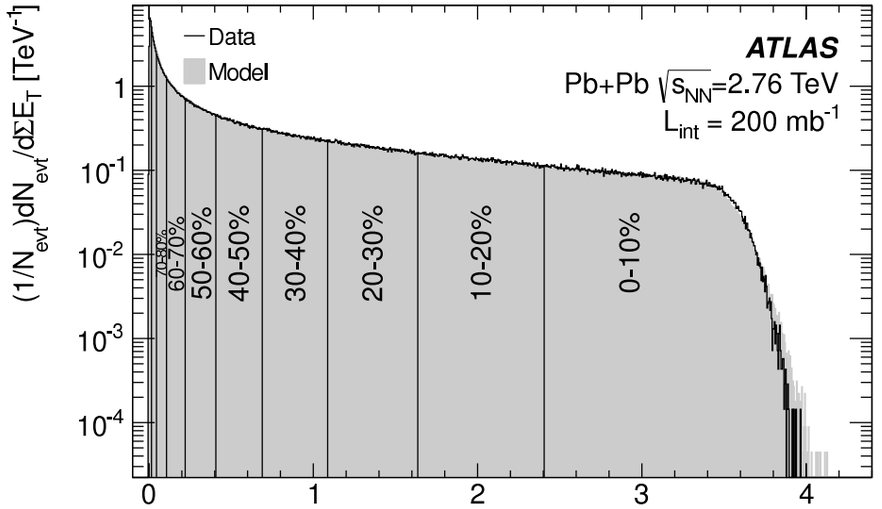
$$N_X / N_{evt} = \sigma_{NN} \times T_{AB}$$

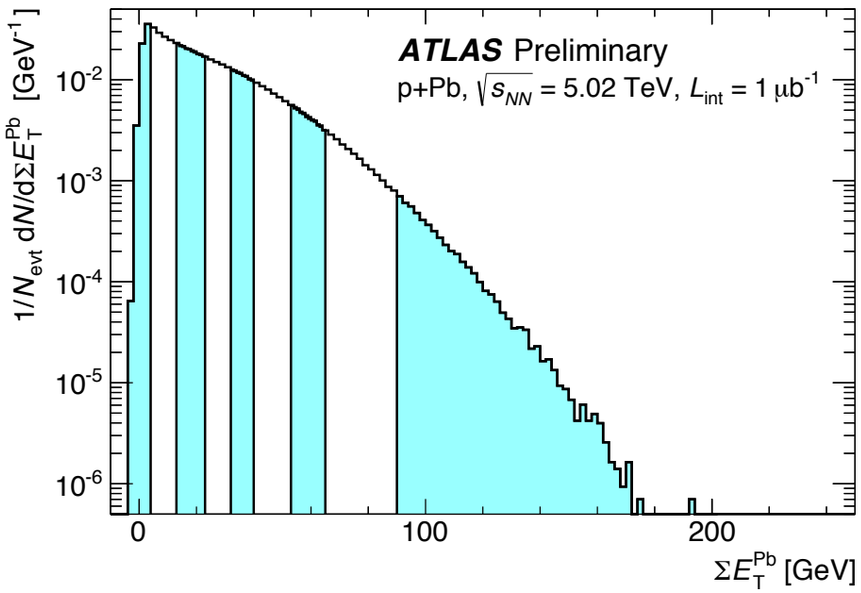
- Strong asymmetries observed in high energy dijets in Pb+Pb, by ATLAS & CMS
  - First direct indications of quenching of jets
- Consistent with previous measurements of hadron suppression, and jet suppression
  - Both observed violation of expected rates of high p_T hadrons and jets
- Electroweak bosons are a crucial check to make sure nuclear modifications to PDFs are not responsible for this effect
- Further studies of jets in Pb+Pb and p+Pb relative to p+p to provide further insight



Data sets

- Two primary data sets discussed in this talk
  - 140 μb^{-1} of Pb+Pb from November/December 2011 run
    - 2.76 TeV in the NN center of mass
  - ~30 nb^{-1} of p+Pb from the January/February 2013 run
    - 5.02 TeV in the pN center of mass, with $\Delta y=0.465$ in proton direction
- Similar triggers in both datasets
  - Muon triggers for W,Z
  - Electron and photon triggers for Z,photon
  - Jet triggers, with full background subtraction at in the ATLAS high level trigger
- Centrality
  - Total E_T in ATLAS FCal (3.2<|eta|<4.9) in Pb+Pb
  - For p+Pb collisions, Pb-going FCal only
  - In both cases, FCal total E_T distribution divided into percentiles, "centrality intervals", to which we attribute $<N_{coll}>$ based on a Glauber Monte Carlo calculation



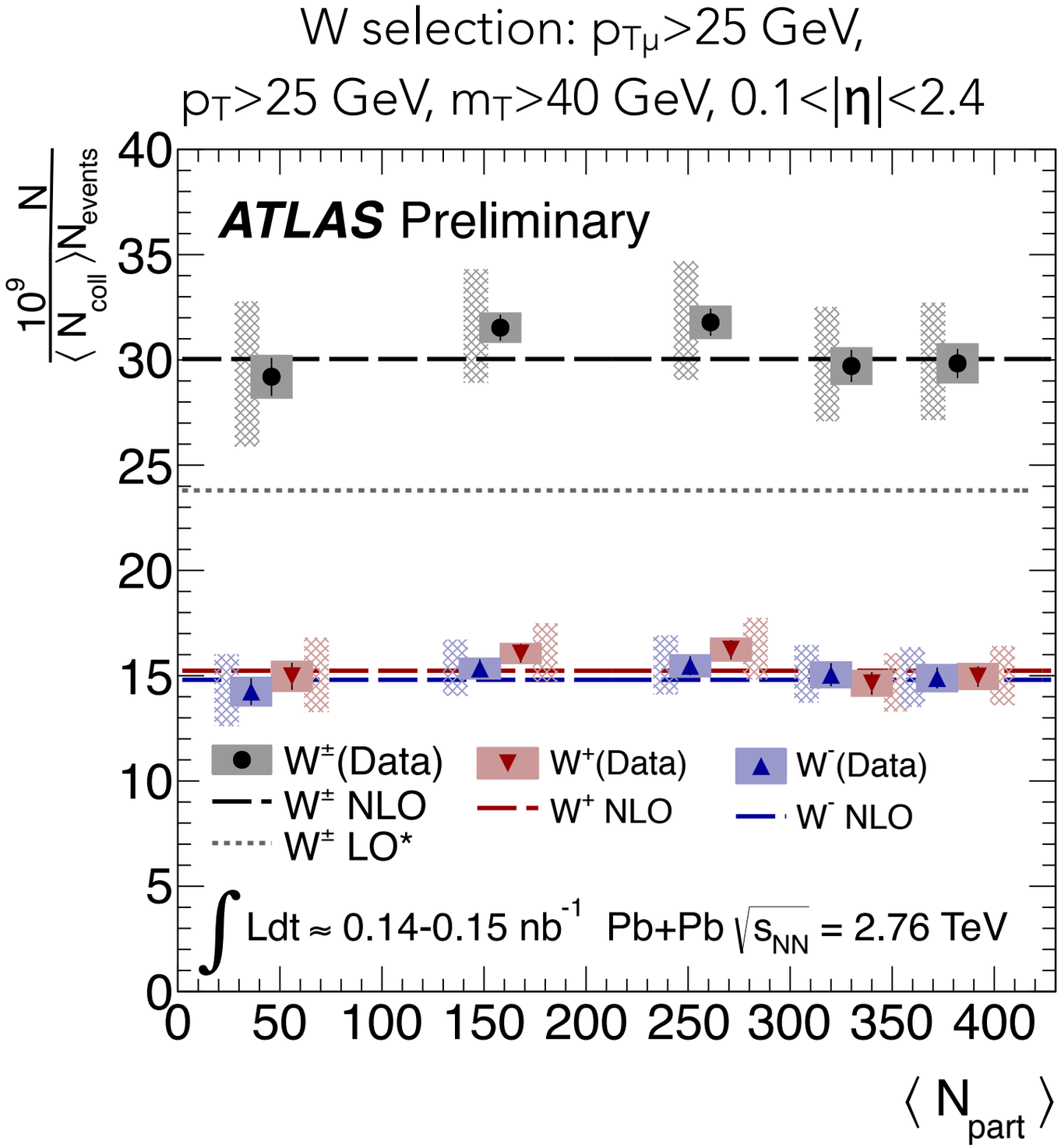


Centrality dependence of W yields

Yield **per binary collision** is approx. constant over 0-80% centrality range: well described by NLO calculations of NN

Highest precision confirmation of T_{AB} scaling to date.

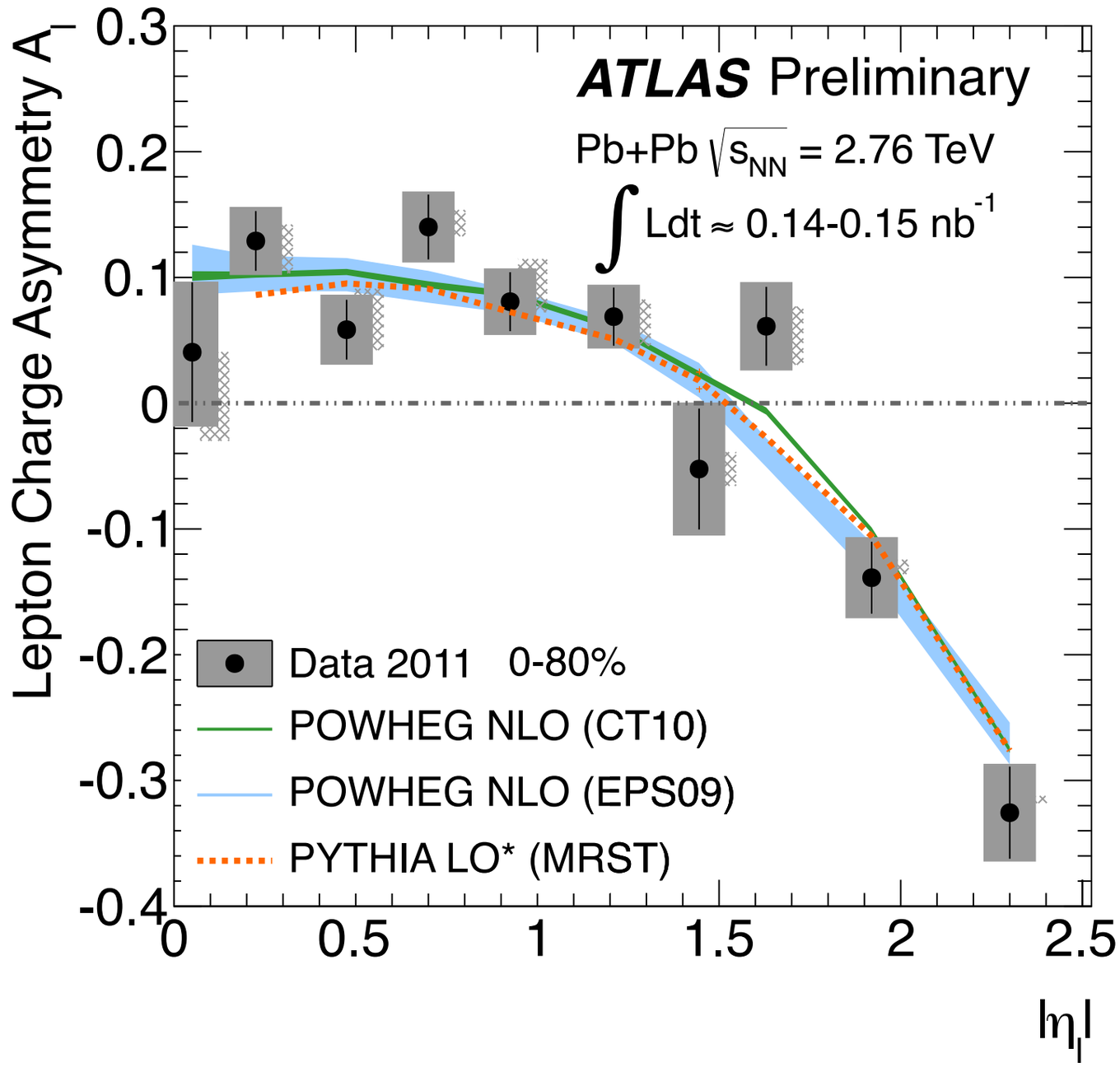
Published Z results give similar conclusions.



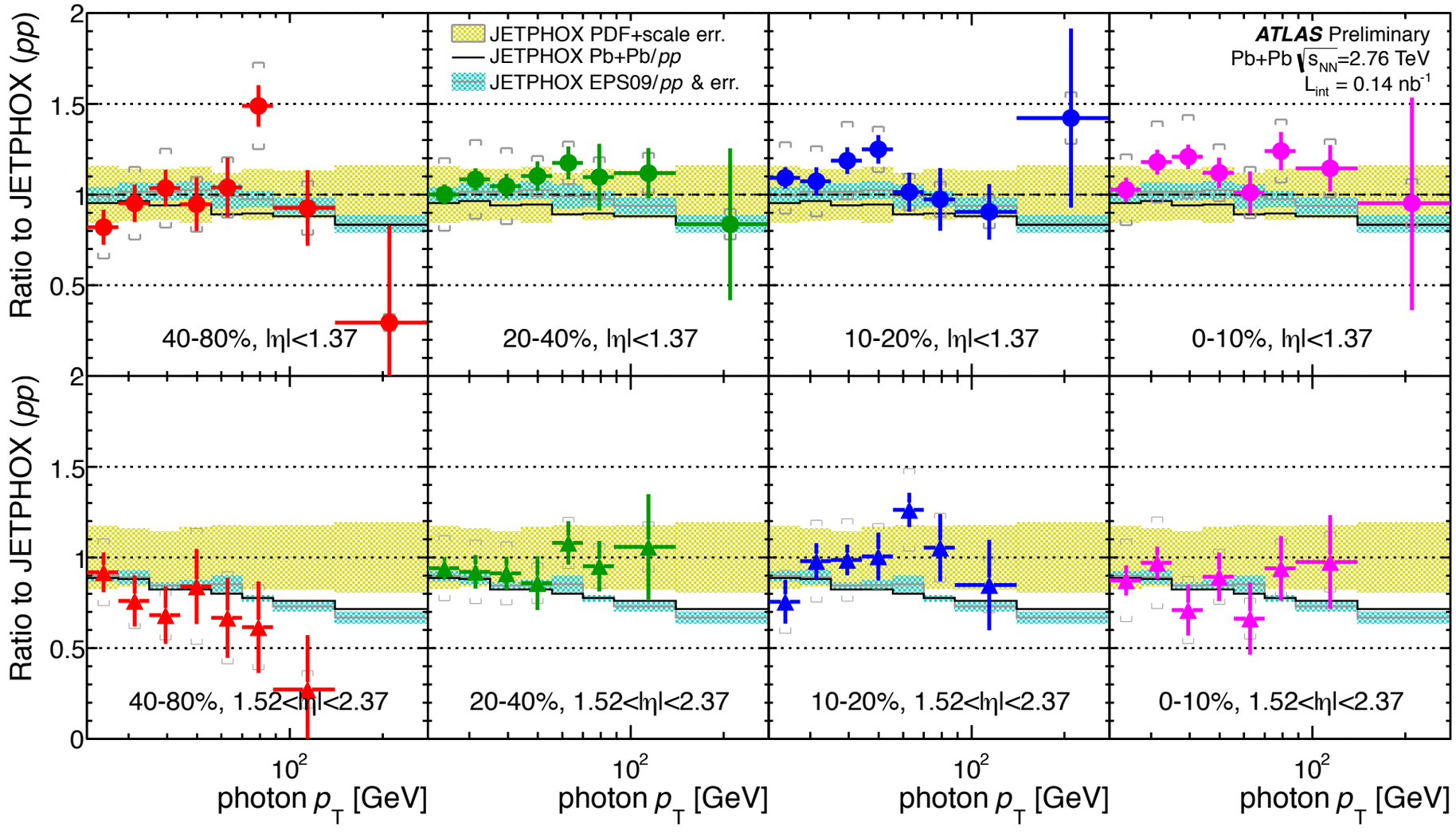
Charge asymmetry

Charge asymmetry vs. lepton η is consistent with both NLO & LO* calculations.

This variable not sensitive to some implementations of nPDFs, but an important check on importance of isospin



Inclusive photon production in Pb+Pb



Photons compared to JETPHOX NLO pQCD calculations (CTEQ6.6, BFG II FFs) run with R=0.3, 6 GeV isolation.

Three configurations: **pp** (unity), **Pb+Pb/pp** (black line), **EPS09/pp** (blue area).

Yellow shaded region is scale & PDF uncertainties, shared with Pb+Pb.

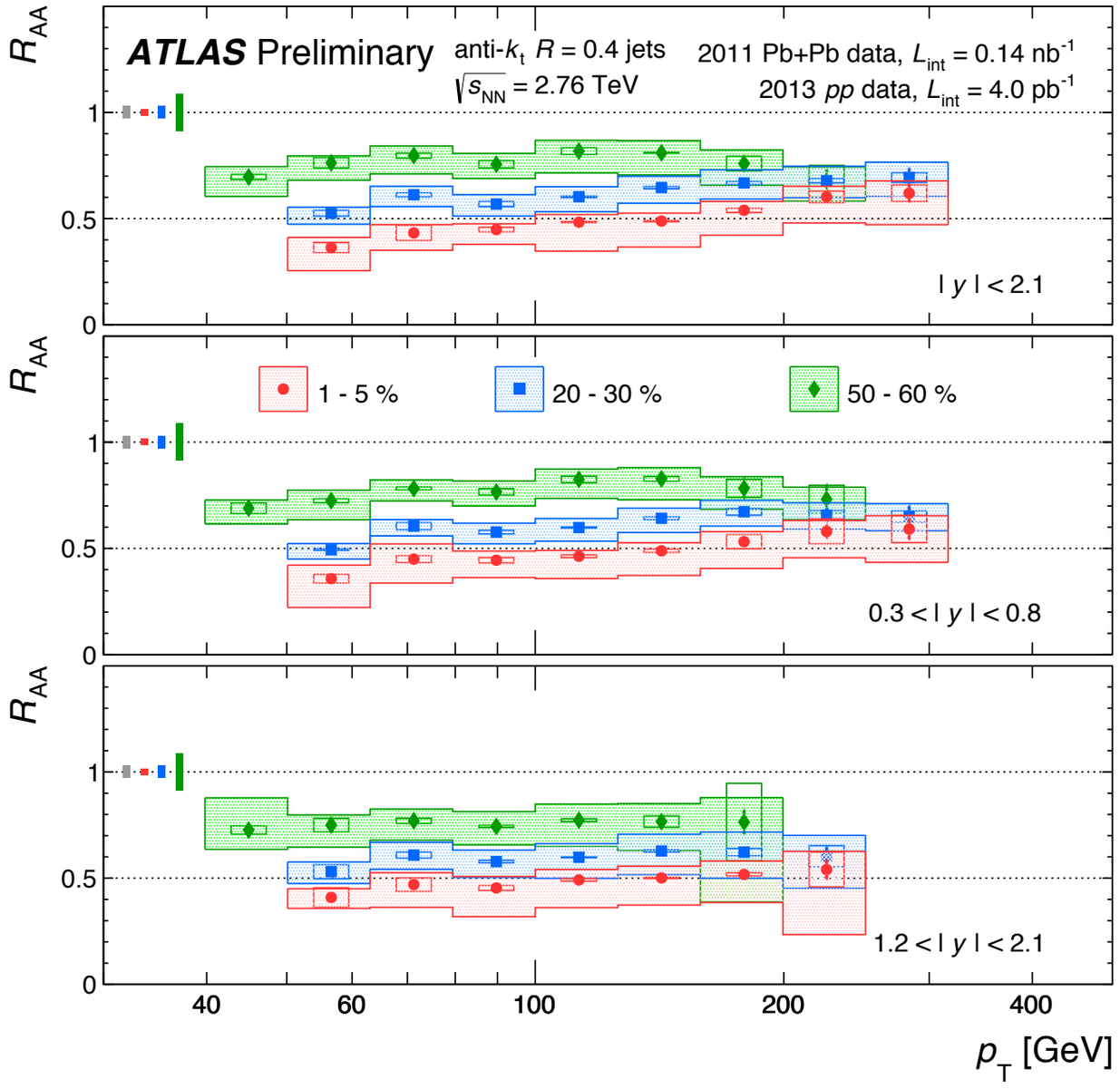
EPS09 errors represented by blue area.

Inclusive jet suppression in Pb+Pb

Inclusive jet rates in Pb+Pb scaled by cross sections, recently measured using 2013 2.76 TeV data

Large (~2x suppression) observed in the most central events, consistent with previous ATLAS measurements of central/peripheral ratios

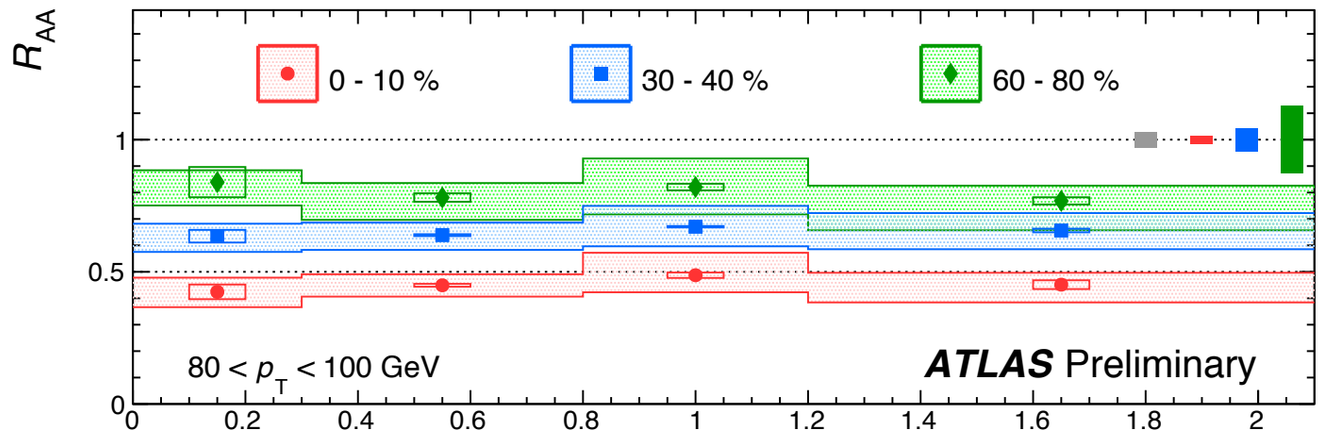
Mild but significant rise at higher p_T, in the more central bins.



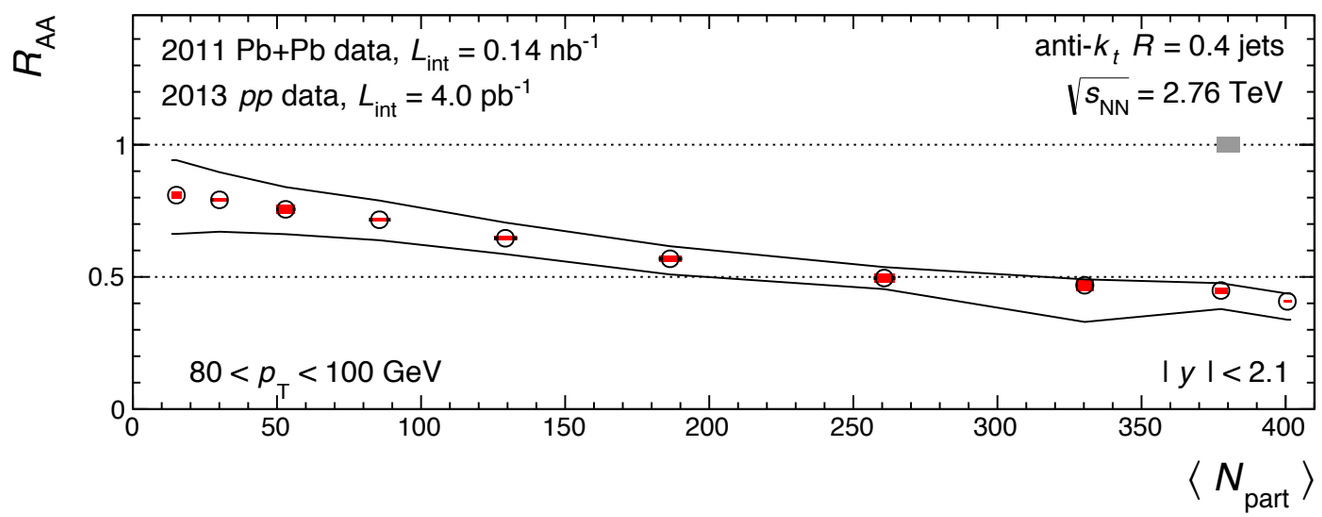
$$R_{\mathrm{AA}} = \frac{\frac{1}{N_{\mathrm{evt}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\Big|_{\mathrm{cent}}}{\langle T_{\mathrm{AA}} \rangle_{\mathrm{cent}} \times \frac{\mathrm{d}^2 \sigma_{\mathrm{jet}}^{pp}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}$$

Jet suppression in Pb+Pb

Very weak dependence on jet rapidity, suggesting no obvious influence of nuclear PDFs

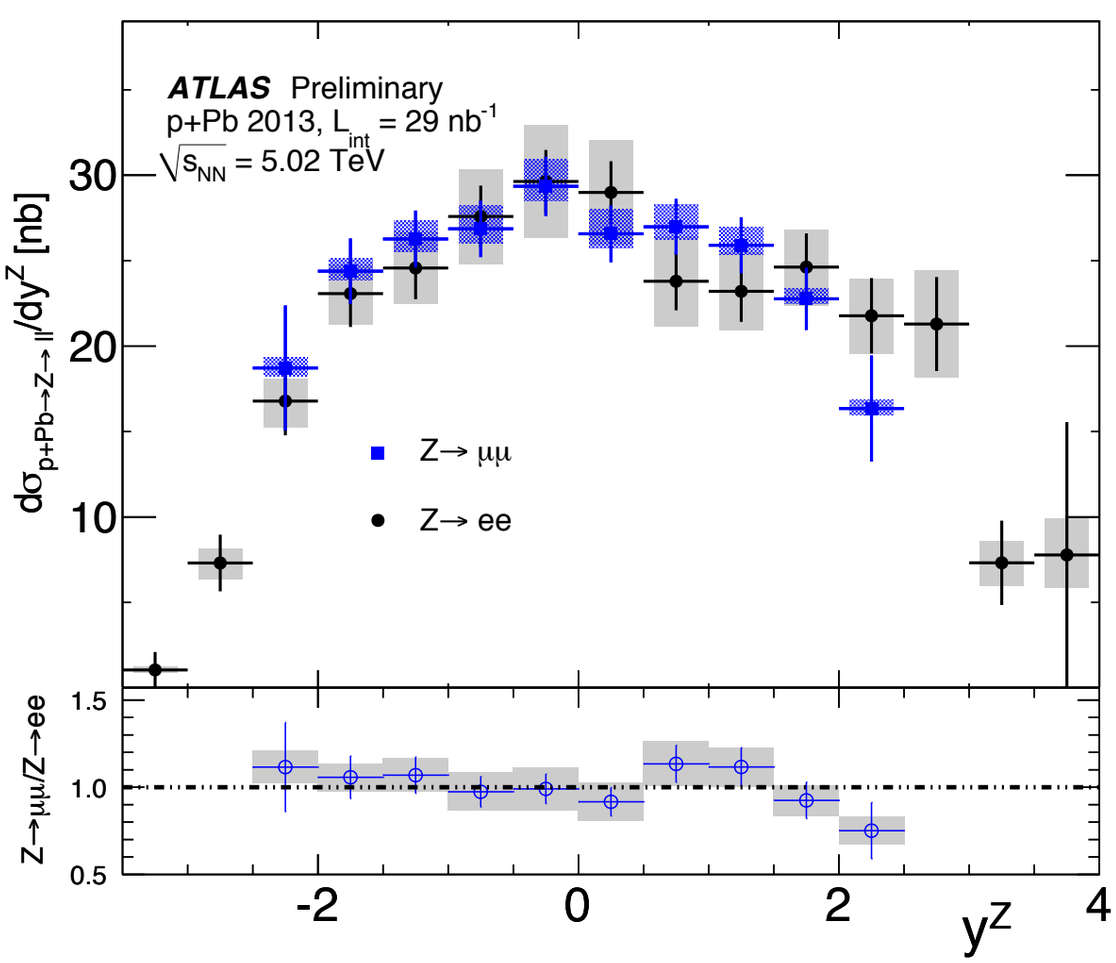


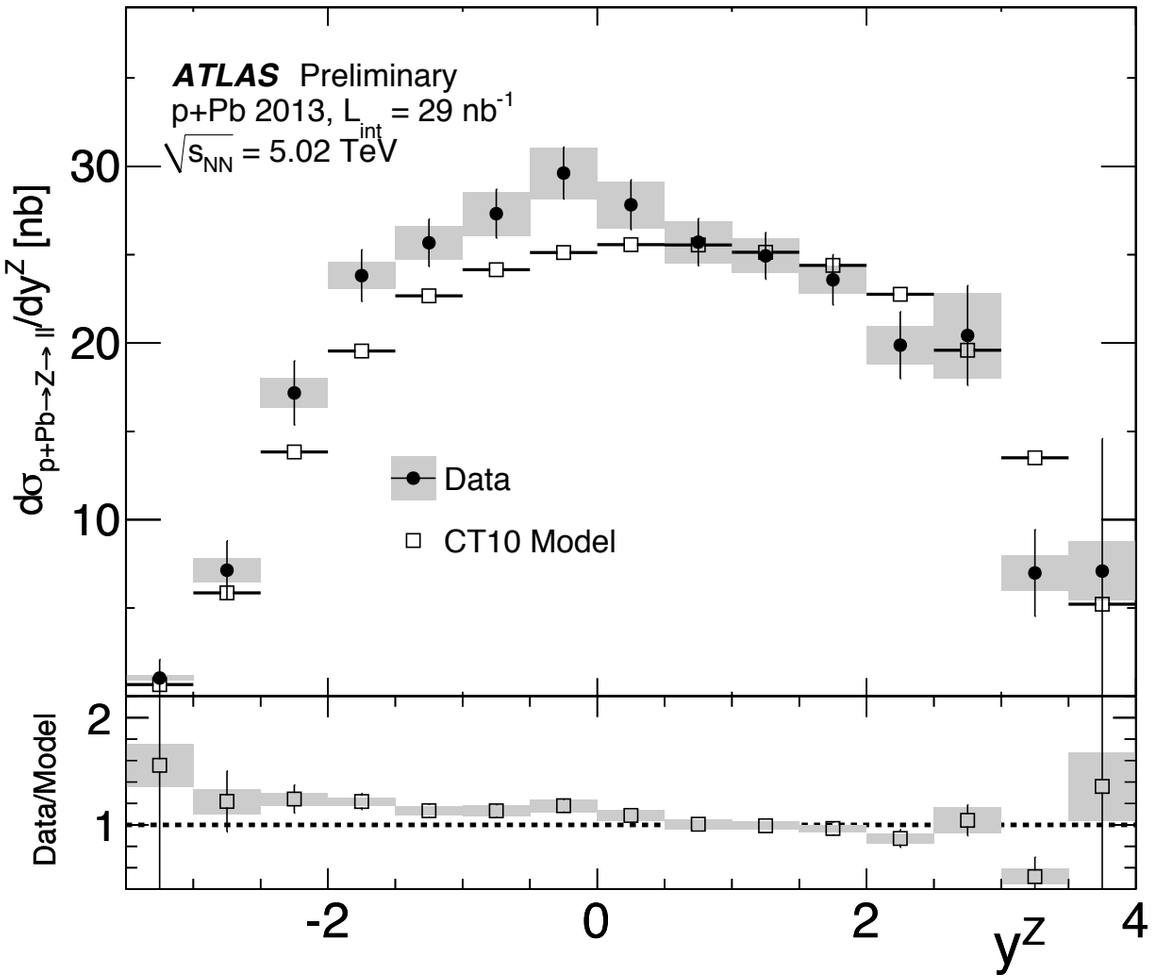
Very strong centrality dependence, with maximal suppression factor of 0.4 in the 0-1% most central Pb+Pb events



Z in p+Pb

forward→





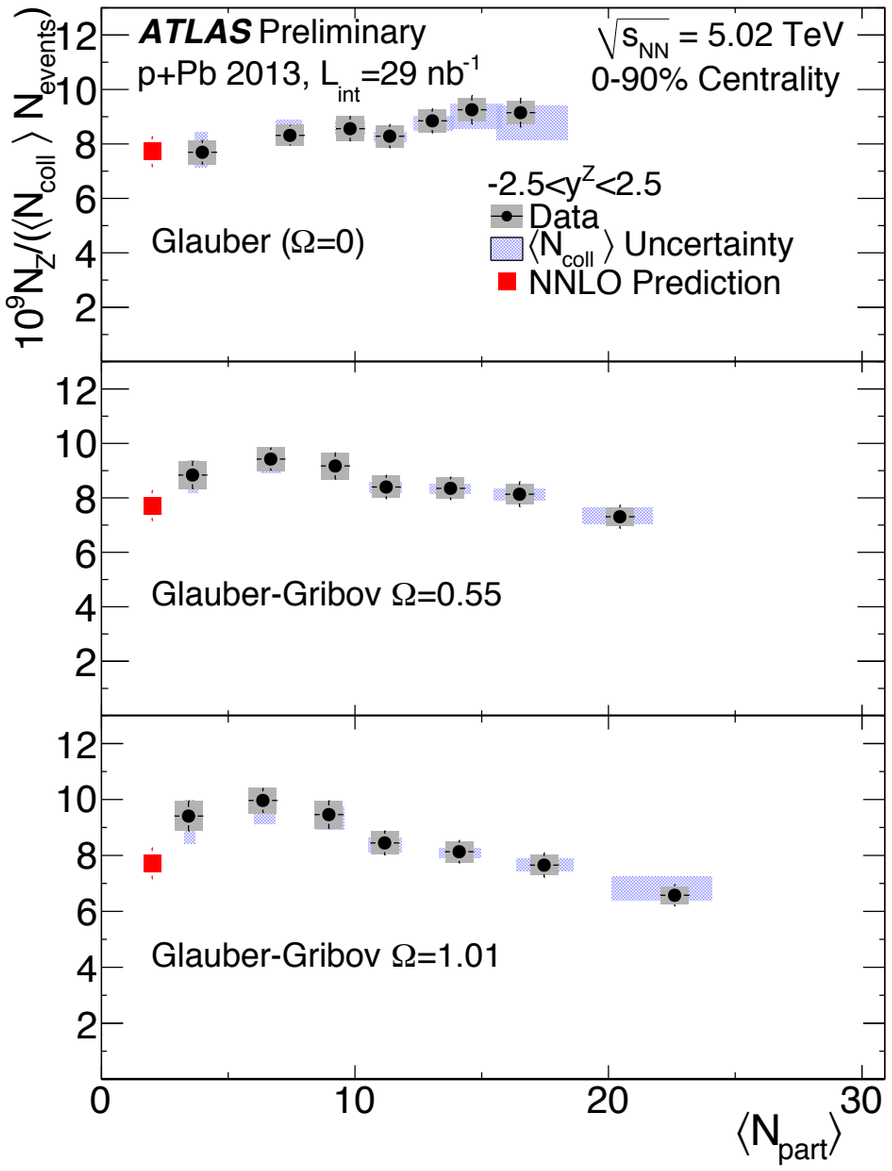
New measurements of p+Pb cross sections.

Good consistency between dielectron and dimuon channels..

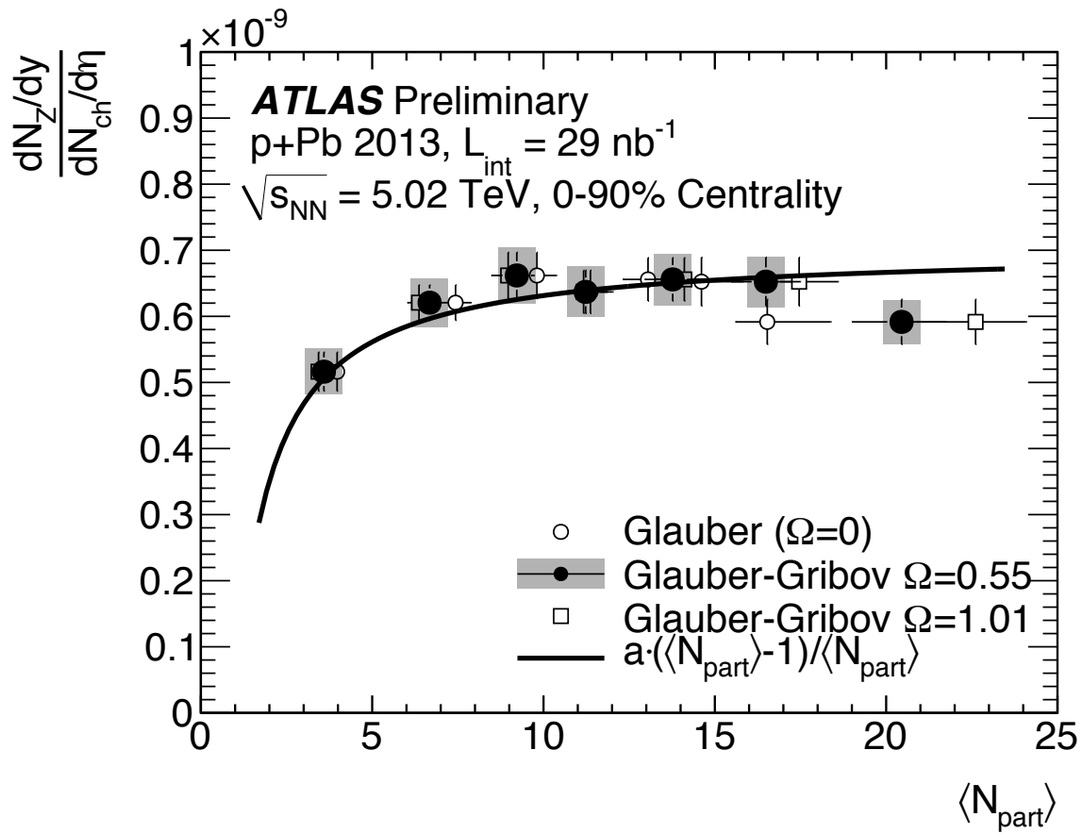
Similar as in Pb+Pb, compared to NNLO calculation using CT10 PDFs.

Small (10-20%) enhancement observed in Pb-going direction

Centrality dependence of Z production



The per collision Z yield has some dependence on details of centrality calculation. ATLAS is exploring effect of a fluctuating σ_{NN}, as suggested by Alvioli and Strikman (2013).

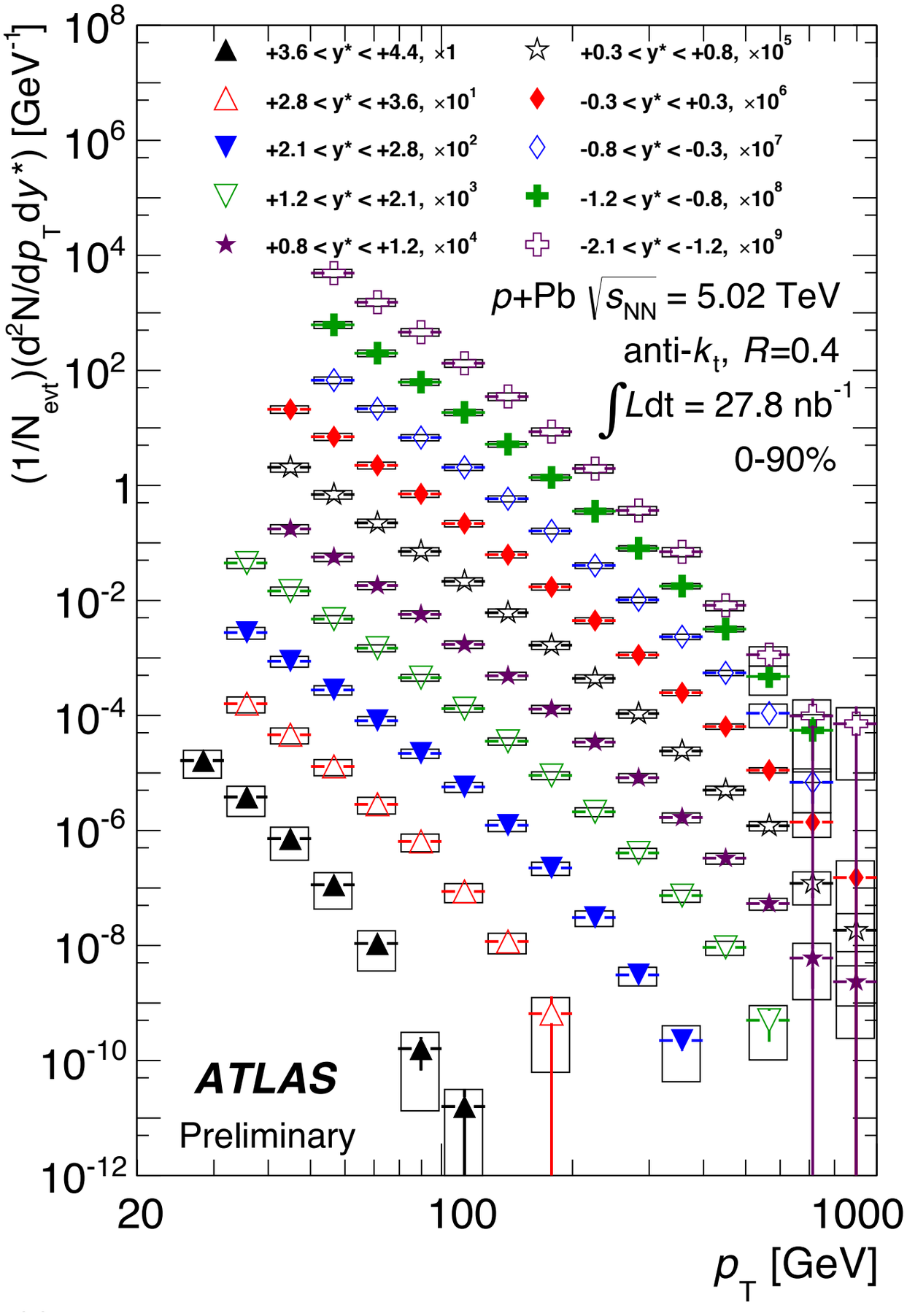


Interesting to compare rates of Z's with inclusive charged particles: scaling less sensitive to details of calculation, and good agreement with data.

Jets in p+Pb

- While some indications of hot, dense matter observed in p+Pb collisions ("double ridge" studied extensively by LHC and RHIC experiments), strong energy loss not expected, due to much shorter transverse path length than in Pb+Pb

- ATLAS has measured jets in p+Pb over a very wide kinematic region



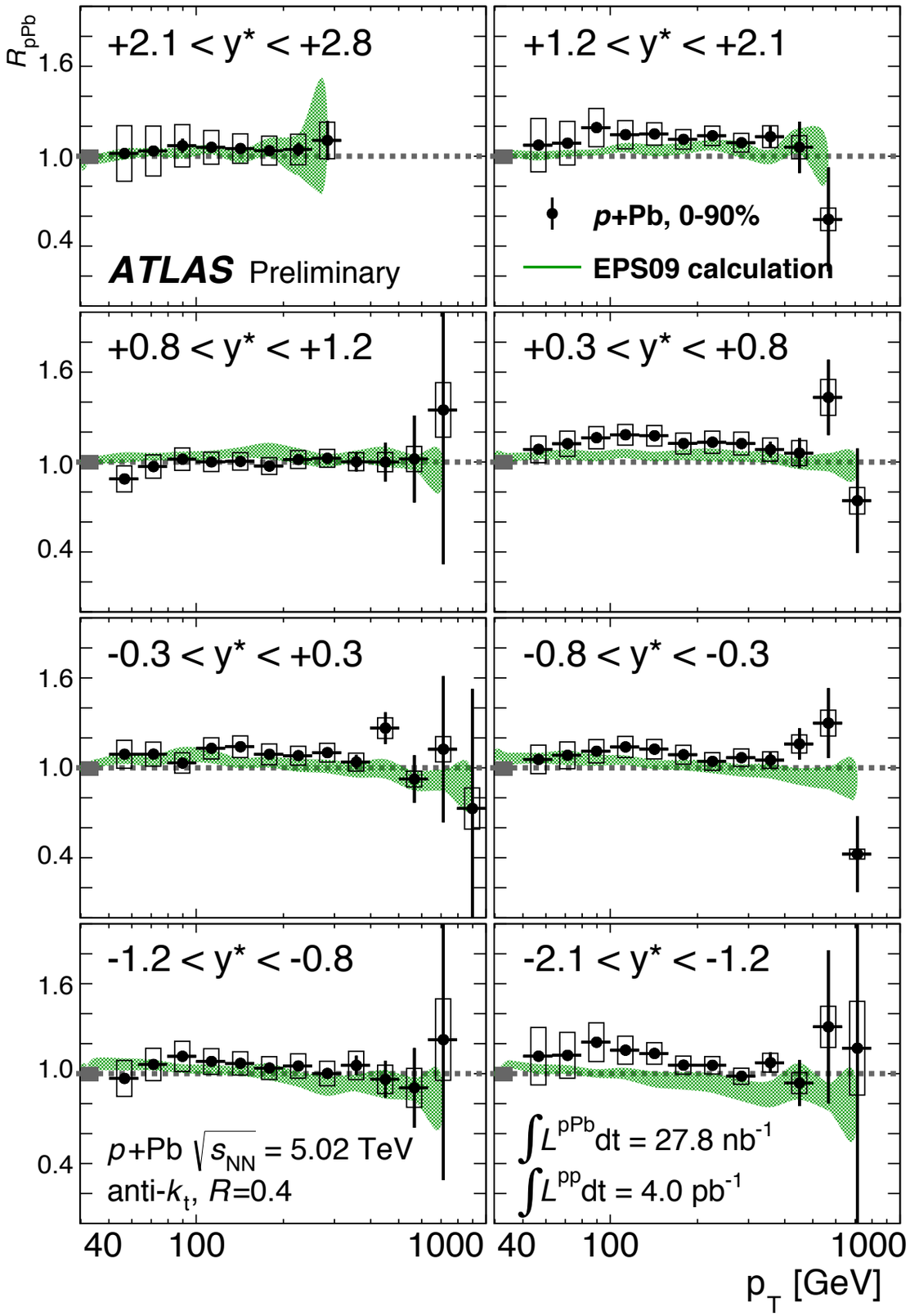
Jet suppression relative to proton-proton collisions

Also using the 2013 p+p data set, interpolated to 5.02 TeV using x_T scaling.

Use of y* (rapidity in CM frame) to account for CM boost in p+Pb relative to p+p

At all rapidities, no suppression seen, with perhaps a small systematic enhancement over pp, consistent with EPS09 calculation (green region)

Forward



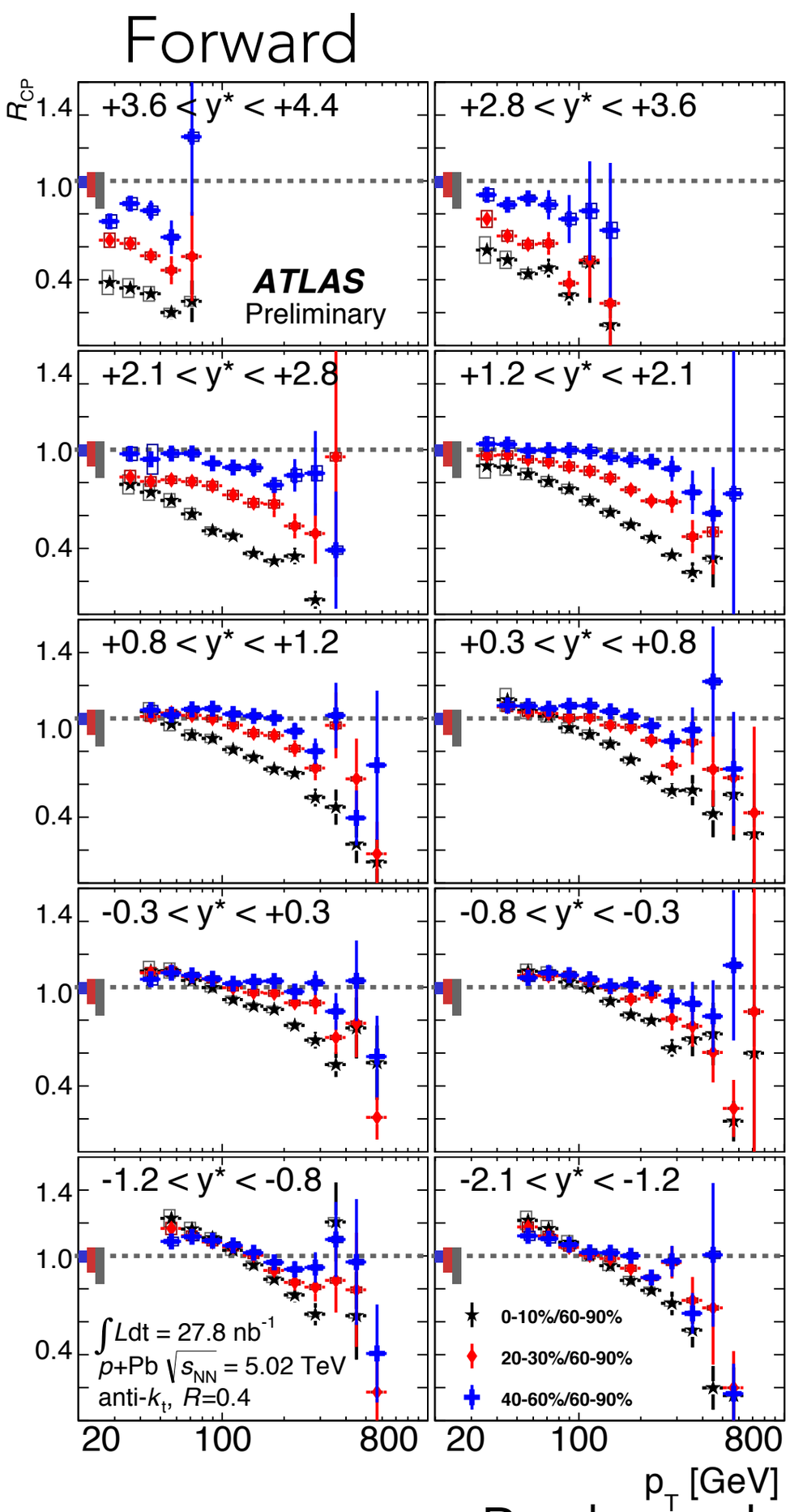
Backward

Central/peripheral ratios in p+Pb

Jet yields in a more-central selection divided by T_{pPb}, relative to same ratio in the 60-90% selection (closest to pp) "R_{CP}"

Strong R_{CP} suppression seen in forward (proton-going) rapidities, increasing w/ centrality

Mysterious given overall scaling for minimum bias!

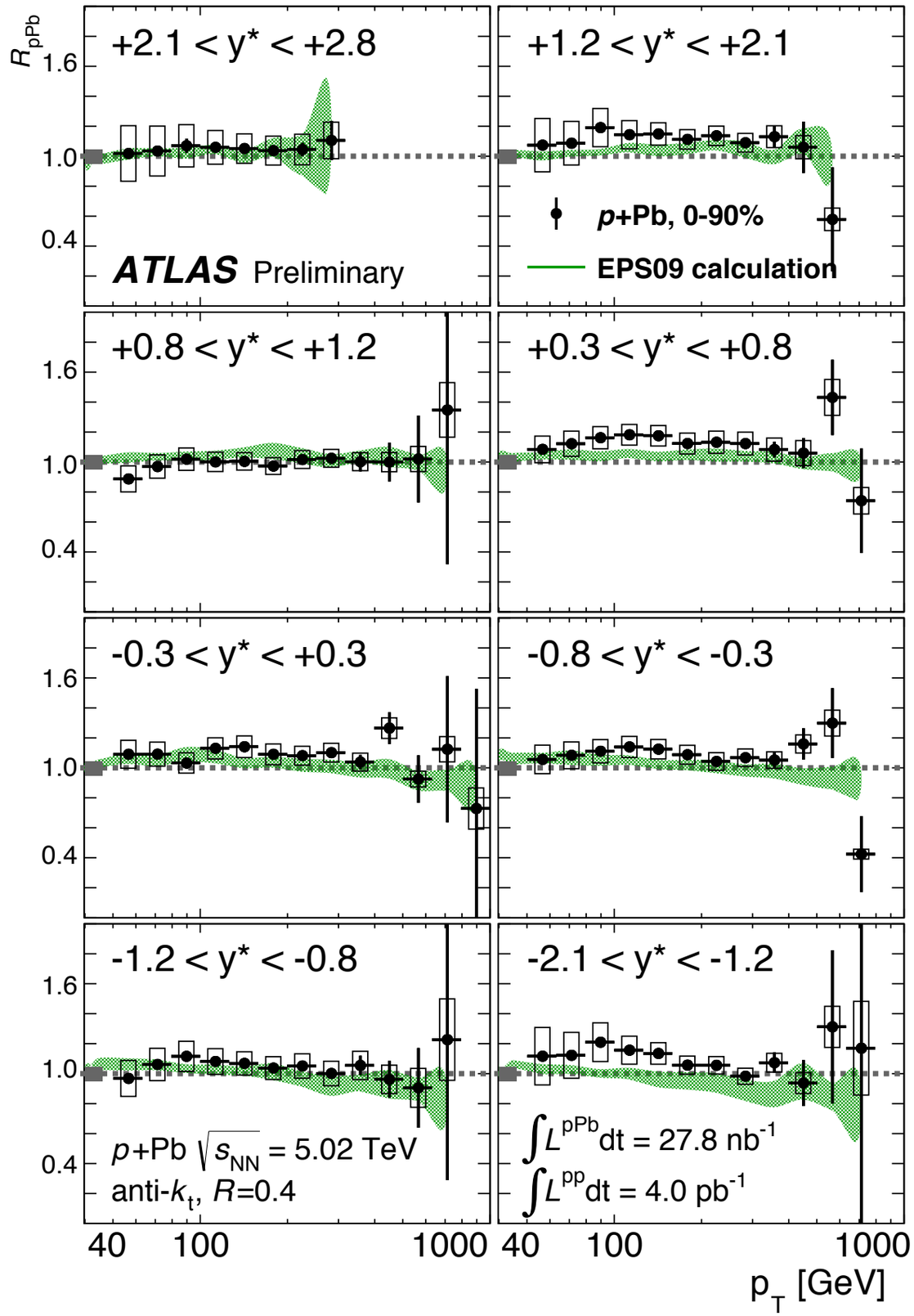


Centrality-selected suppression relative to pp

Central/peripheral ratios are consistent with 0-90% R_{pPb} based on observed centrality-selected R_{pPb}:

Jets are suppressed in more central events, but enhanced in peripheral events!

Forward



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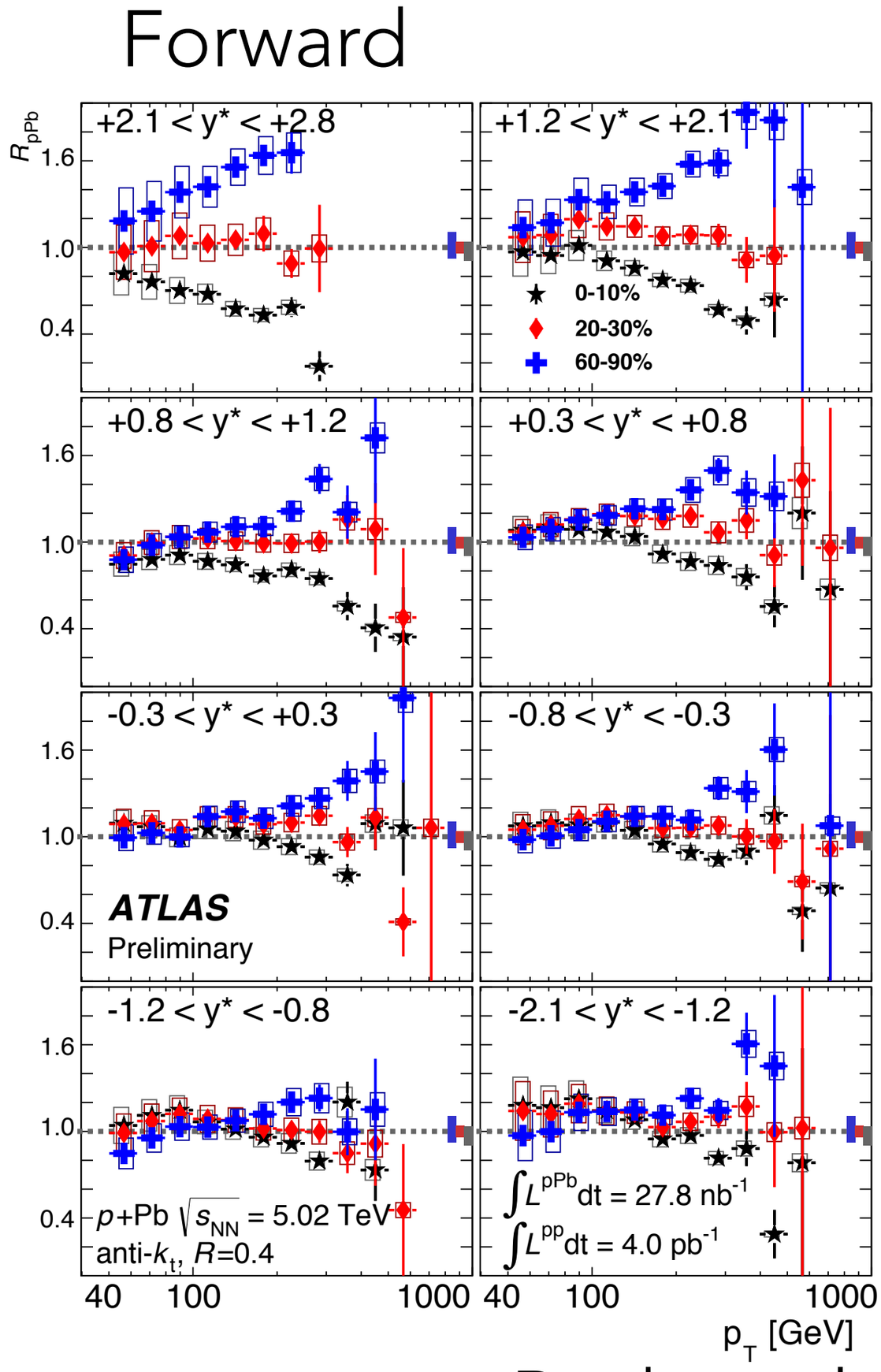
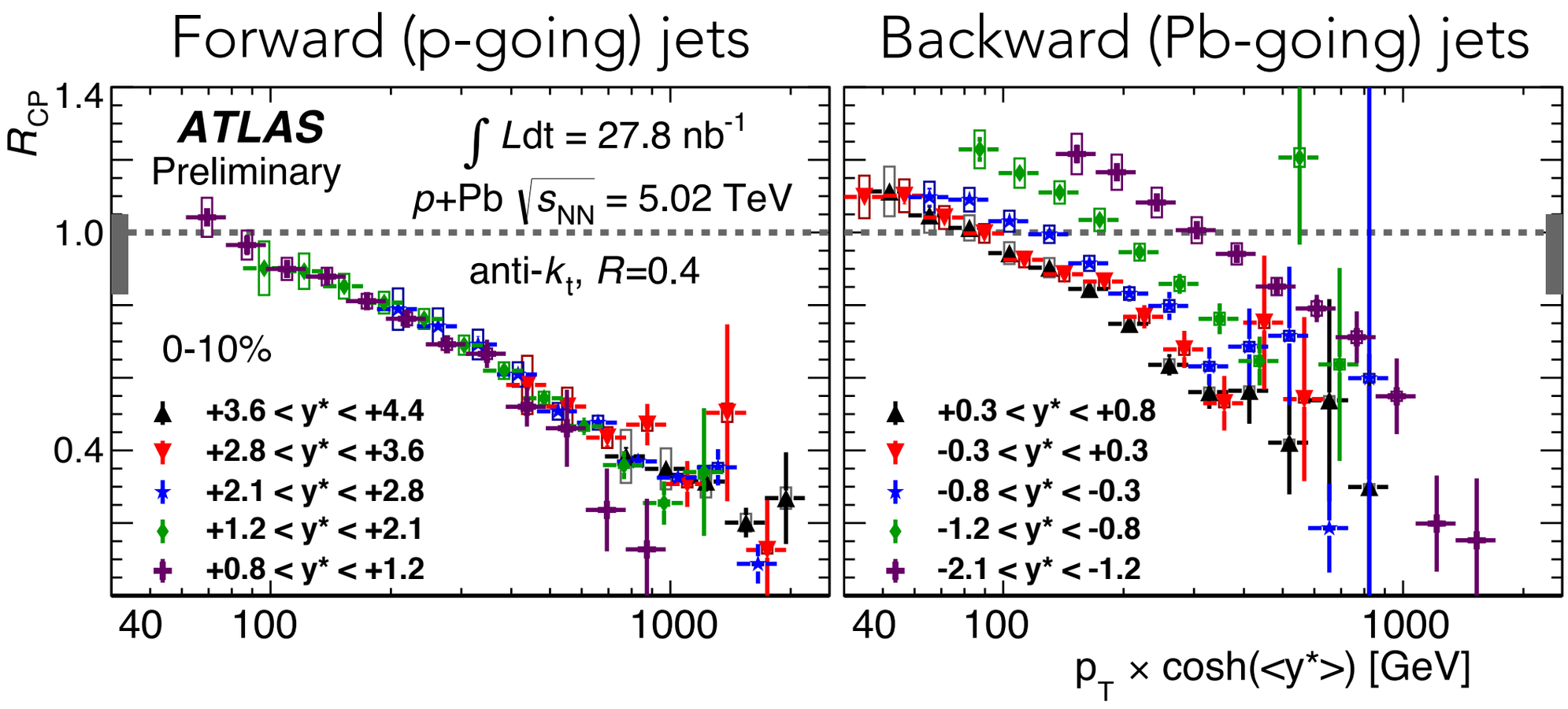


What controls the relative suppression in p+Pb?



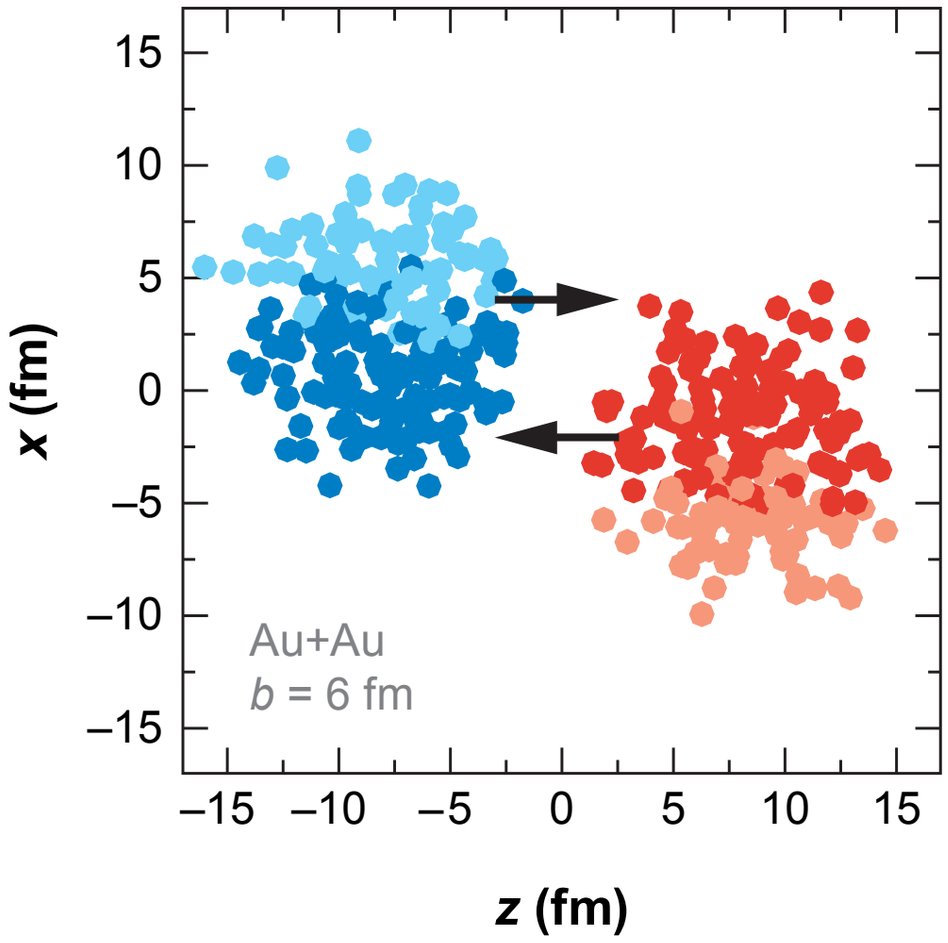
An **unexpected scaling** has been observed for the central/peripheral ratios by plotting the R_{CP} in all rapidity selections as a function of jet momentum: Unifies behavior of relative jet suppression at all rapidities. Very different from Pb+Pb — possibly a correlation of the jet kinematics with the centrality observable in p+Pb?

Conclusions

- Brief review of jet and EW results from Pb+Pb and p+Pb
- Pb+Pb shows two characteristic features
  - Electroweak production is produced linearly with the number of binary collisions, no obvious effect (yet) of nuclear PDFs.
  - Jets are strongly suppressed in more central events, by more than a factor of two.
- p+Pb shows very different features
  - Z production shows an unexpected rapidity asymmetry
  - Jets show no overall suppression, but a non-trivial centrality dependence of jet rates relative to expectation: possible correlation between jet kinematics and event structure?
  - p+Pb is evidently not a trivial reference!
- Many interesting questions for LHC Run 2!

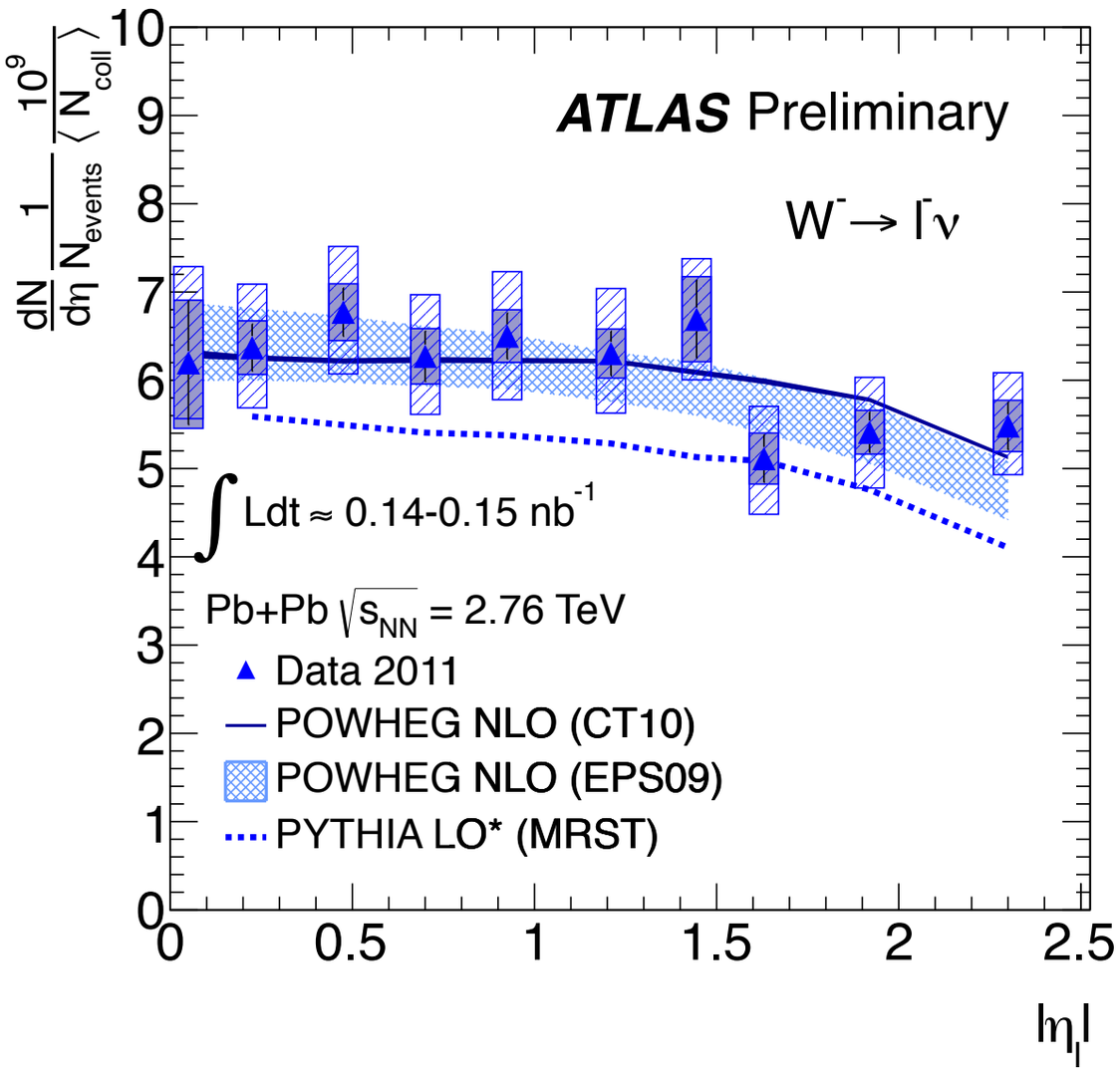
Hard process rates in Pb+Pb and p+Pb

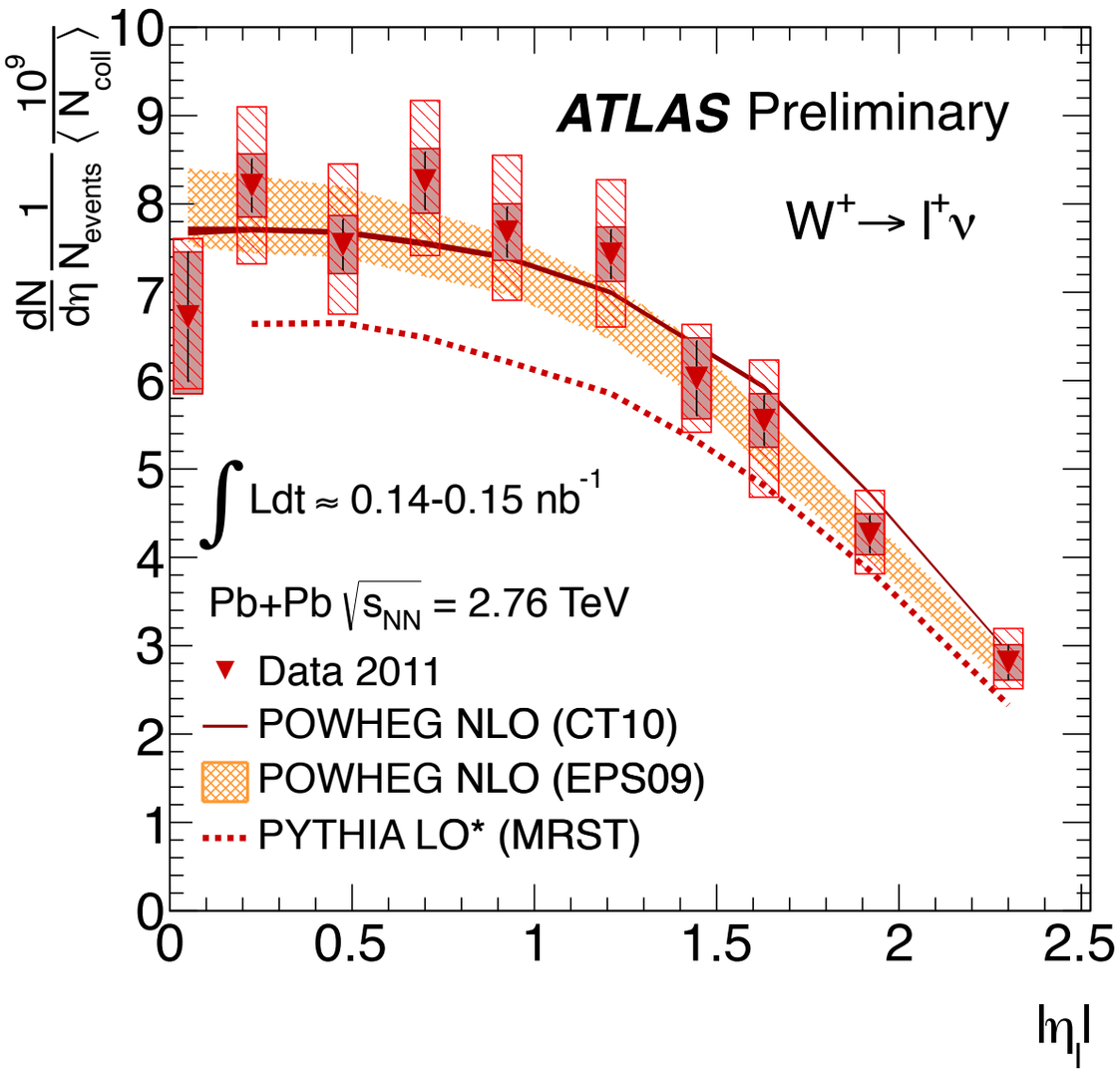
- ATLAS observed strong asymmetries in dijets in the earliest Pb +Pb data
  - Clear indication of jet energy loss in the hot, dense matter formed at the LHC
  - Observed in inclusive jet and hadron suppression by all LHC experiments.
- Centrality is critical to understanding the production rates of hard processes in collisions involving nuclei
  - Expect yields of a hard process to scale as the pp cross section, times the "mean nuclear thickness function", T_{AB}
  - In practical calculations, we use Glauber model for nuclei to calculate $T_{AB} = \langle N_{coll} \rangle / \sigma_{NN}$, where N_{coll} is the number of binary collisions, and σ_{NN} is the nucleon-nucleon total inelastic cross section
  - Since $\langle N_{coll} \rangle$ also scales linearly with σ_{NN}, T_{AB} is a purely geometric quantity which expresses the incoming flux of partons in an A+B collision
- In both p+Pb and Pb+Pb we use processes which are not affected by the hot, dense medium to test whether or not our basic assumption is correct
  - Importance of W/Z/photons!



W production

W selection: $p_{T\mu}$>25 GeV, $\not{p}_T$>25 GeV, m_T>40 GeV





η distributions of leptons from W decays in Pb+Pb

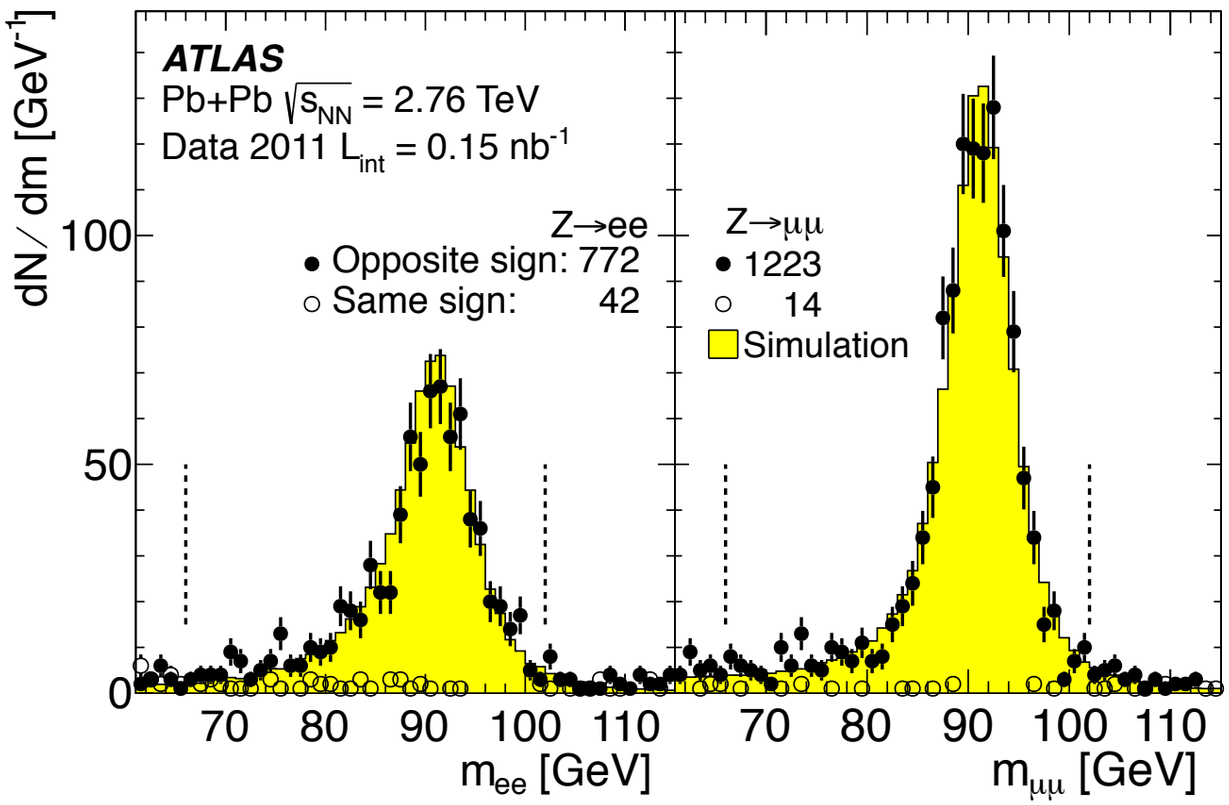
efficiency corrected to fiducial region same as selection cuts:

LO* & NLO QCD calculations account for isospin in PDFs.

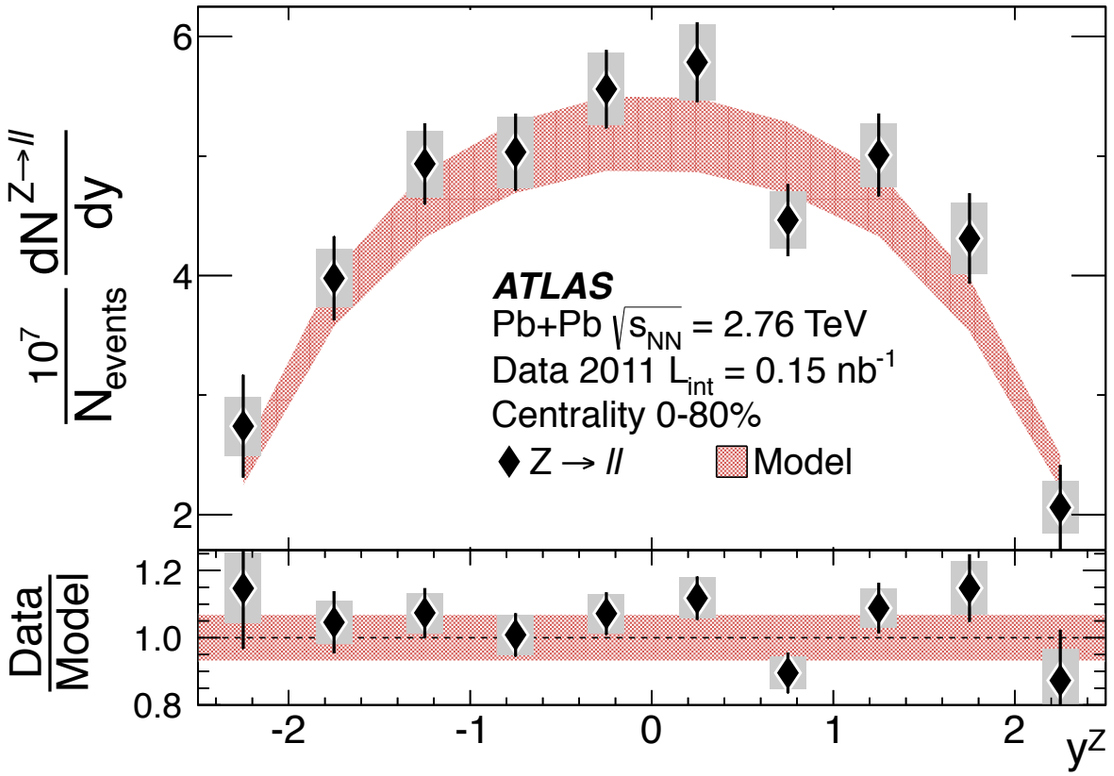
Excess of negative charge reflects d quarks from neutrons.

Hard Probes: Z boson yields vs. y

Phys. Rev. Lett 110, 022301 (2013)



Z bosons reconstructed in both dielectron and dimuon channels: lineshape well described by ATLAS simulations



Z rapidity distribution well described by PYTHIA pp dN_Z/dy scaled to NNLO cross section